

Salmon Hatcheries for the 21st Century: A Model at Warm Springs National Fish Hatchery

DOUGLAS E. OLSON

*U.S. Fish and Wildlife Service, Columbia River Fisheries Program Office
1211 SE Cardinal Court, Suite 100, Vancouver, Washington 98683, USA*

BOB SPATEHOLTS

*Department of Natural Resources
Confederated Tribes of the Warm Springs Reservation of Oregon
Post Office Box C, Warm Springs, Oregon 97761, USA*

MIKE PAIYA

*U.S. Fish and Wildlife Service, Warm Springs National Fish Hatchery
Post Office Box 790, Warm Springs, Oregon 97761, USA*

DONALD E. CAMPTON

*U.S. Fish and Wildlife Service, Abernathy Fish Technology Center
1440 Abernathy Road, Longview, Washington 98632, USA*

Abstract.—Salmon hatcheries in the Pacific Northwest continue to produce fish for harvest, largely to fulfill a mitigation function. Fisheries management struggles with the need to integrate this harvest opportunity from hatcheries with wild fish conservation. Warm Springs National Fish Hatchery demonstrates a program that balances this need to help offset salmon losses, provide fisheries, and protect wild fish. The U.S. Fish and Wildlife Service and Confederated Tribes of the Warm Springs Reservation of Oregon initiated the hatchery program in 1978 with wild, native fish from the Warm Springs River. The goal is to cooperatively manage hatchery operations to balance harvest opportunities with protection of wild fish populations and their inherent genetic resources. The management objectives are (1) to produce spring Chinook salmon *Oncorhynchus tshawytscha* for harvest in tribal subsistence and sport fisheries, (2) to preserve the genetic characteristics of the native population both in the hatchery and in the naturally spawning component of the integrated population, (3) to manage impact on wild fish to levels which pose a minimum risk, and (4) to develop and implement a hatchery operations plan to achieve both the harvest and conservation goals for the Warm Springs River Chinook population. To determine if these objectives are met, data on harvest, escapement, recruitment, spawning success, fish health, survival, run timing, age and size at return, and juvenile production characteristics have been collected to monitor changes over time and to compare performance of wild and hatchery origin fish. These data have been cooperatively collected by the Confederated Tribes of the Warm Springs Reservation, Oregon Department of Fish and Wildlife, and U.S. Fish and Wildlife Service for more than 25 years. Every 5 years, a hatchery operation plan has been developed based on this monitoring. The following list of actions are identified in the 2002–2006 hatchery operations plan and are measures for protecting the natural population while operating the hatchery for harvest augmentation: (1) Mass marking and coded-wire tagging of hatchery production for selective fisheries, broodstock management, and hatchery evaluations; (2) Selecting broodstock to mimic wild fish run timing; (3) Incorporating wild fish in the hatchery broodstock using a sliding scale; (4) Limiting the number of hatchery fish allowed to spawn naturally; (5) Operating an automated passage system for returning adults to reduce handling of wild fish; (6) Replacing the hatchery's water intake structure to meet new screening criteria to protect juvenile fish; (7) Simulating environmental and biological factors in the hatchery environ-

ment to match natural production; (8) Managing fish health at the hatchery; (9) Assessing ecological interactions between wild and hatchery fish; and (10) Determining the reproductive success of hatchery fish spawning in the stream. The monitoring and management of Warm Springs National Fish Hatchery demonstrates a sustainable program, integrating the need for both harvest and wild fish conservation.

Introduction

Wild salmon and steelhead *Oncorhynchus mykiss* returns to the Columbia River were historically estimated between 10 and 16 million adult fish (WDFW and ODFW 2002). Soon after arrival of the first European settlers in the Northwest, extractive resource use, including overharvest, hydropower, irrigation, mining, and logging, began to deplete salmon populations and their habitat. Fish hatcheries were built to mitigate for the losses of wild salmon production (Lichatowich 1999). Artificial propagation of anadromous salmonids has been a prominent feature of fisheries management in the Columbia River basin now for more than 100 years (Brannon et al. 1999). As part of this compensation, in the year 2000, 148 million juvenile fish from hatcheries were released into the Columbia River (Fish Passage Center, www.fpc.org). In that same year, approximately 75% of the 1.7 million adult salmon and steelhead returning to the Columbia River originated from hatcheries (WDFW and ODFW 2002).

Hatcheries were primarily built, and are still important, to support harvest. For example, the 2000 sport fishery for coho salmon *O. kisutch* in the popular Buoy 10 area of the lower Columbia River yielded a harvest of 21,500 hatchery coho salmon from 72,500 angler trips (WDFW and ODFW 2002). Hatcheries also continue to support important commercial and tribal fisheries (Pastor 2000; S. K. Olhausen, poster presentation from the symposium covered by this volume).

Hatcheries also play an important role in conservation. For example, hatchery production of steelhead trout *O. mykiss* from Dworshak National Fish Hatchery in the Snake River basin of Idaho are produced to compensate for construction of Dworshak Dam on the North Fork Clearwater River. While not operated or originally designed as a conservation facility, Dworshak National Fish Hatchery conserves a unique population that would have been extirpated as a result of blocking all fish from their spawning grounds (Chandler and Bjornn 1989). More recently, with listing of many populations of salmon and steelhead under the Endangered Species Act (ESA), hatcheries have been specifically used for conservation purposes (Hard et al. 1992). Conservation roles asked from

hatcheries range from captive breeding (Schiewe et al. 1997), to population maintenance (Bugert et al. 1995), to supplementation of natural production (Carmichael and Messmer 1995).

To meet conservation requirements, fisheries management has identified the need to distinguish and differentially manage hatchery and wild origin fish, have run-size prediction tools and fishing regulations to protect wild stocks and to manage appropriate hatchery production, and, most important, have sufficient habitat to support natural production. Managers also recognize that hatcheries used for conservation purposes need to incorporate wild fish in the hatchery broodstock, to trap and spawn broodstock to incorporate phenotypic traits representative of the natural population in terms of run timing, age, length, and sex composition, and to minimize artificial selection and domestication of the hatchery stock in the hatchery environment. Implementing the above three hatchery management requirements for conservation describes what Don Campton (U.S. Fish and Wildlife Service, regional geneticist) refers to as a genetically integrated broodstock. The purpose of this genetic integration is to minimize genetic divergence between hatchery broodstock and naturally spawning populations. This definition has also been adopted by the Hatchery Science Review Group in the state of Washington and by the Northwest Power and Conservation Council's Artificial Production Review and Evaluation in the Columbia River basin (HSRG 2000; NPPC 2003).

Artificial propagation has been successful in supporting harvest and increasing abundance of salmon, but not without risks to natural fish. The risks of hatchery operations on wild and native populations and the environment are often described as ecological risk (Pearsons and Hopley 1999), including predation, competition, disease, behavioral anomalies, and habitat modification due to hatchery structures and operations; and genetic risks (Reisenbichler and Rubin 1999; Campton 1995), including loss of diversity, fitness, domestication, and artificial selection. There are also management risks, such as overfishing and the masking of the status of natural populations by abundant hatchery populations (HSRG 2000).

Managing the risks to natural fish while achieving harvest augmentation and mitigation goals is the challenge faced by managers. In this paper, we will describe the spring Chinook salmon *O. tshawytscha* program at Warm Springs National Fish Hatchery. We will describe how operations at Warm Springs National Fish Hatchery have evolved over the last 25 years to consider genetic, management, and ecological risks to native fish populations. We will describe how the program has considered genetic risk by (1) selecting broodstock representative of the complete run and normal run timing, (2) incorporation of a proportion of natural fish in the hatchery broodstock, (3) avoidance of artificial selection in broodstock selection protocols and in hatchery practices, and (4) limiting the number of hatchery-origin adults allowed to spawn naturally. Management risks are addressed by (1) marking all hatchery-origin fish with an easily identified external mark (the adipose fin clip); (2) using the external mark to identify fish for broodstock selection, spawning escapement, and fishery regulation; (3) using coded-wire tags to assess hatchery operations, including survival, homing, and straying; and (4) monitoring the escapement, recruitment, and survival of hatchery and natural-origin fish. Ecological risks are evaluated in ongoing investigations, including (1) releasing juvenile hatchery fish of similar size and physiological development as their natural counterpart, (2) conditioning juvenile fish to natural rearing conditions, (3) managing hatchery releases (both juveniles and adults) to consider the carrying capacity of receive-

ing waters, (4) managing fish health at the hatchery, and (5) modifying hatchery intake screens and adult passage facilities for improved passage conditions for juvenile fish and to reduce handling, disease, and delays of natural spawners.

Study Area and Program Overview

Warm Springs National Fish Hatchery is located at river kilometer (rkm) 14 on the Warm Springs River, within the Warm Springs Indian Reservation, in north-central Oregon (Figure 1). The Warm Springs River enters the Deschutes River at rkm 135, which enters the Columbia River 330 km from the Pacific Ocean. The Deschutes River is upstream of two major dams on the Columbia River, Bonneville (rkm 235) and The Dalles (rkm 308) dams. Currently all anadromous fish production is blocked at rkm 161 on the Deschutes River by the Pelton/Round Butte dams, mitigated by hatchery production of spring Chinook salmon and steelhead trout at Round Butte state fish hatchery. Natural production of spring Chinook salmon now occurs in only two streams within the Deschutes River watershed, the Warm Springs River, and Shitike Creek (rkm 155 on the Deschutes River). The Warm Springs River drainage encompasses 846 km² and Shitike Creek 122 km² (ODFW 1997). More than 95% of the spring Chinook salmon natural production in the Deschutes River watershed occurs in the Warm Springs River.

Warm Springs National Fish Hatchery is funded and operated by the U.S. Fish and Wildlife Service

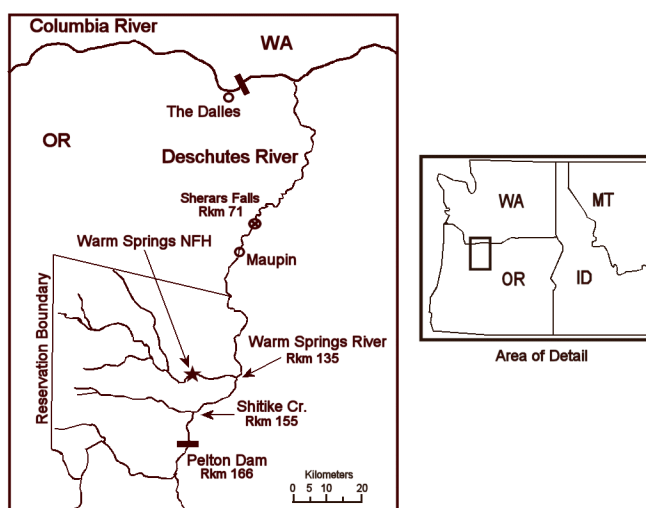


Figure 1. The lower 166 km of the Deschutes River watershed and location of Warm Springs National Fish Hatchery on the Warm Springs Indian Reservation, Oregon.

(Service). The purpose of the hatchery program is to cooperatively manage the hatchery with the Confederated Tribes of the Warm Springs Reservation of Oregon (Tribe) to provide spring Chinook salmon harvest opportunities and to conserve wild fish populations (Olson et al. 1995). Although a primary objective is to produce fish for harvest, maintaining wild fish traits in the hatchery and stream environment (run timing, size, age, and broodstock composition) and managing affects on wild fish to very low, acceptable levels (as measured by escapement, straying, recruitment, spawning success, and fish health) are equally important.¹

Since the start of the program in 1978, a hatchery operations plan has been jointly developed, endorsed by technical staff, and signed by policy representatives from both the Service and Tribe. The plan has been reviewed and updated every 3–5 years to reflect desired objectives, operational experience, and technological developments. In addition, management of genetic and ecological risks from hatchery operations on Endangered Species Act listed populations is addressed in a hatchery and genetic management plan drafted by the Service (USFWS 2004).

Hatchery Broodstock, Juvenile Production, and Adult Return Goals

Hatchery production has ranged from 200,000 to 1.2 million spring Chinook salmon, 1978–2004. The current objective is to collect 630 adult broodstock for release of 750,000 juvenile fish, split as 10% fall subyearling and 90% spring yearling release into the Warm Springs River at the hatchery site. Prior to release, all juvenile fish at the hatchery are marked with an adipose fin clip and coded-wire tag to identify them as Warm Springs hatchery fish. Broodstock and juvenile production goals are set to provide an adult return of 2,250 or more hatchery spring Chinook salmon to the mouth of the Deschutes River for harvest and escapement. The escapement objective for wild spring Chinook salmon is 1,300 or more adults upstream of Warm Springs National Fish Hatchery.

Broodstock Management

A barrier dam across the Warm Springs River at the hatchery site directs all upstream migrating fish into

the hatchery ladder and catch ponds. From the catch ponds, fish are either passed upstream or retained and placed in broodstock holding ponds. Hatchery and wild fish are enumerated, collected for broodstock, and sampled at the hatchery throughout their return, from the end of April through September.

From 1978 through 2002 ($n = 25$ years), the percentage of wild fish in the broodstock has averaged 31%. Initial guidelines (1978–1981) were to utilize one-third of the wild return or about 450 fish for hatchery broodstock. During the first 4 years of production, 100% of the broodstock was the local indigenous stock, and during the first 10 years of operation (1978–1987), wild fish continued to contribute a significant portion to the hatchery broodstock, averaging 68%, but in the last 10 years (1993–2002) has only averaged 3% (Figure 2).

Our stated goal during the last 10 years was to incorporate 10% wild fish into the hatchery broodstock; however, because of low wild fish escapement (<1,300 adults) in most years, less than 10% was incorporated. To address this problem, the 2002–2006 hatchery operation plan was updated and the goal restated as *achieve a 10-year average of 10% wild fish in the hatchery broodstock*. To accomplish this, a sliding scale for incorporating wild fish into the broodstock was established based on total wild fish returns (Table 1). In years with less than 800 returning wild adult fish, no wild fish are taken into the hatchery for broodstock and all wild fish are passed upstream for natural production. If escapement of wild fish exceeds 800, an increasing proportion of the hatchery broodstock may be wild, based on the sliding scale. For example, if between 1,300 and 1,399 wild fish are predicted to return to the Warm Springs River, then 10% of the total broodstock (63 fish) can be wild fish. The sliding scale goes up to 20% wild fish only if escapement exceeds 2,300 wild fish. The total number of wild fish utilized for broodstock does not exceed 5% of the wild fish in the natural spawning population (Table 1).

For the actual spawning protocol, the intent is to utilize a spawning population of 630 fish and to use a 1:1 male to female spawning ratio. When the number of returning males is less than the number of females, the male to female ratio may become 1:2. When less than 400 broodstock are available, in order to increase effective population size, the number of eggs taken from each female is divided in half and each half fertilized with gametes from a different male. Males are used with more than one female only as often as necessary to fertilize the eggs of all females. Fish that are

¹ A description of statistical tests used for comparisons between wild and hatchery fish can be found in Zar (1974). Significance of statistical analyses were reported at the $p < 0.05$ level.

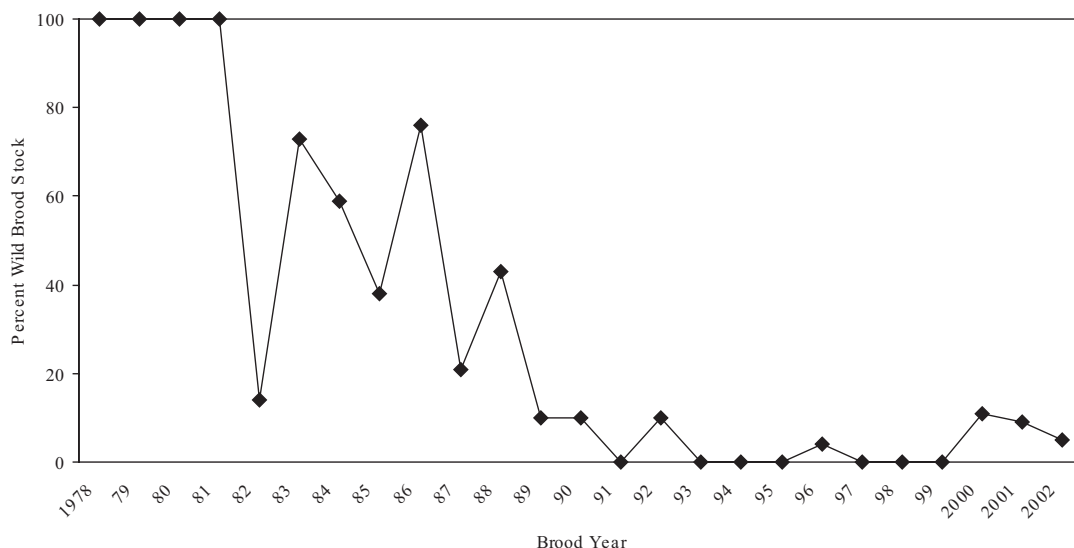


Figure 2. Percentage of wild spring Chinook salmon used for broodstock at Warm Springs National Fish Hatchery, 1978–2002.

60 cm or longer fork length are considered adults and fish less than 60 cm fork length are considered jacks. Between 2% and 5% of the broodstock are fish less than 60 cm fork length, based on the percentage of jacks in the wild population and their estimated contribution during spawning. The objective is to main-

tain life history characteristics of the hatchery stock similar to that of the wild fish.

Hatchery fish surplus to production are distributed to the Tribe for subsistence and those fish not suitable as food are buried. Since 2000, approximately 200 hatchery adults have also been released to a nearby stream (Shitike Creek) for supplementation. The behavior and reproductive success of these outplanted hatchery fish is being evaluated (Hand et al. 2003). In some years, adult broodstock from Warm Springs have also been transferred to Round Butte state fish hatchery on the Deschutes River and vice versa. Both hatcheries produce Warm Springs stock spring Chinook salmon from the Deschutes River.

Table 1. Sliding-scale for incorporating wild spring Chinook salmon into the hatchery brood stock at Warm Springs National Fish Hatchery.

Projected wild escapement	Number of wild fish for broodstock	Percent of hatchery brood contributed by wild fish
<800	0	0
800–899	31	5
900–999	38	6
1,000–1,099	45	7
1,100–1,199	50	8
1,200–1,299	57	9
1,300–1,399	63	10
1,400–1,499	69	11
1,500–1,599	76	12
1,600–1,699	82	13
1,700–1,799	88	14
1,800–1,899	95	15
1,900–1,999	100	16
2,000–2,099	107	17
2,100–2,199	113	18
2,200–2,299	120	19
>2,300	126	20

Run Timing

Run timing of hatchery and wild fish was compared by examining cumulative returns, separated by 1-month intervals. We examined 13 years (1987–1999) of return timing data collected at the hatchery. Wild and hatchery fish returned to the Warm Springs River from late April through September, spawning from late August through September. Most wild and hatchery fish returned to the Warm Springs River by late June. However, in the early part of the run, hatchery fish typically had a 1–2-week lag in their return when compared to wild fish (Figure 3). For example, by May 31 of each year, an average 64% (15% SD) of the wild and 49% (14% SD) of the hatchery fish had returned to the

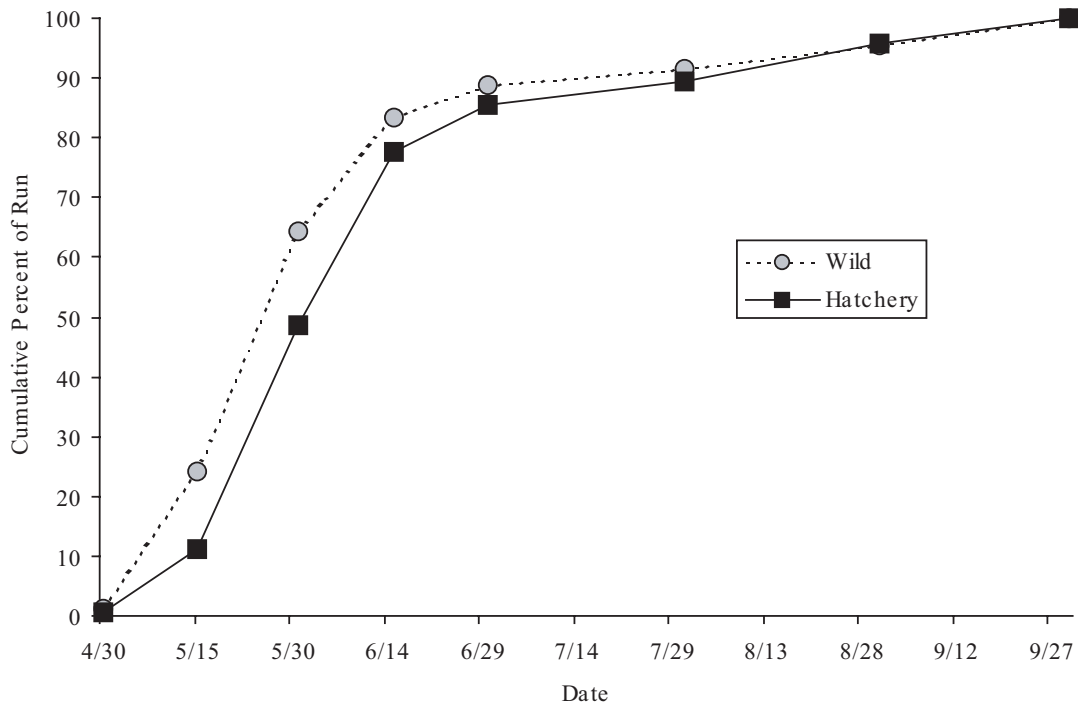


Figure 3. Cumulative run timing (%) of wild and hatchery spring Chinook salmon returning to the Warm Springs River, 1987–1999.

Warm Springs River, with wild fish having an earlier run timing 12 out of 13 years, 1987–1999 (Figure 4). By June 30 of each year, an average 89% (5% SD)

of the wild and 85% (5% SD) of the hatchery fish had returned. A significant difference was found in cumulative run timing between wild and hatchery

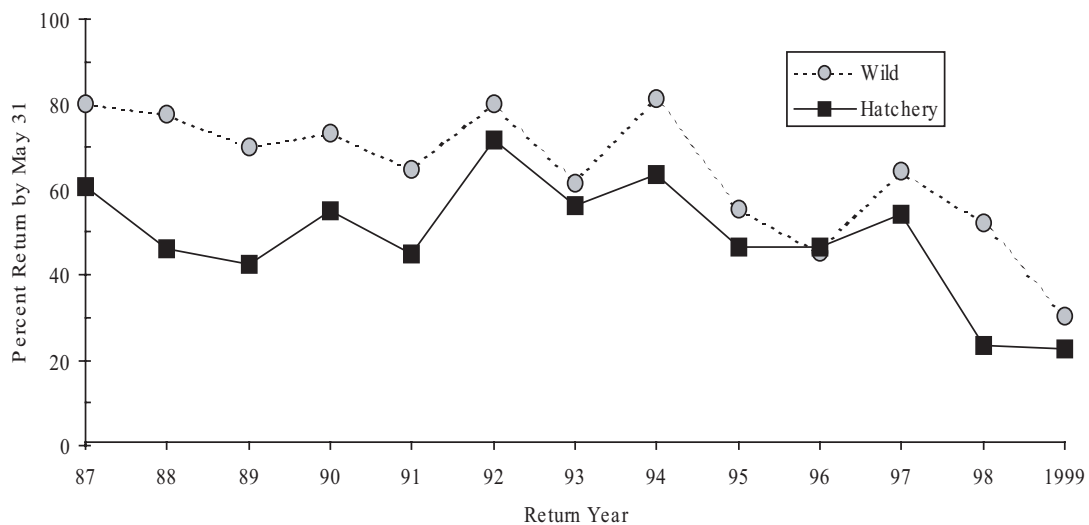


Figure 4. Annual variation in percent return of wild and hatchery spring Chinook salmon to the Warm Springs River by May 31, 1987–1999.

fish ($P < 0.001$, Chi-square = 396). Recognizing this difference, the broodstock collection strategy was modified to not only collect fish throughout their natural return, but to also specifically recognize the average run timing observed for wild fish (Table 2).

Run timing is also affected by age structure of the returning population. Older year-classes returned earlier on average as compared to age-3 jacks. Examining years 1982–1999, as of May 31, $55\% \pm 15\%$ SD of the hatchery fish returned when excluding “jack” fish <61 cm as compared to $47\% \pm 15\%$ SD of the hatchery fish returned when including all size-/age-classes. Jack-size fish arriving later than adult-size fish is reported in other natural and hatchery populations as well, as shown in Columbia River counts at Bonneville Dam (Fish Passage Center, www.fpc.org). Monitoring will continue in order to determine if different management actions result in producing similar run timing between wild and hatchery fish, as well as age structure at return, as discussed in the following section.

Age Structure

Age-class strength was compared for wild and hatchery spring Chinook salmon returning to the Deschutes River. Brood years 1978 through 1997 were examined, combining escapement to the Warm Springs River and Deschutes River harvest to estimate Deschutes River returns. Both wild and hatchery stocks (80% and 82%, respectively), returned predominately as age-4 adults (Figure 5). However, the wild stock

Table 2. Hatchery broodstock collection based on average run timing of wild spring Chinook salmon.

Date	Cumulative number of broodstock	Cumulative percent
May 8	76	12
May 15	151	24
May 23	284	45
May 31	422	67
Jun 8	485	77
Jun 15	542	86
Jun 23	561	89
Jun 30	573	91
Jul 31	586	93
Aug 25	630	100

had more fish returning at age 5, 16% for wild and 7% for hatchery fish, whereas the hatchery stock returned more age-3 fish, 5% for wild and 11% for hatchery fish. Hatchery fish returned more age-3 jacks 15 out of 20 years, 1978–1997, especially in years 1983 and 1984 (Figure 6). A significant difference was found in age distribution between wild and hatchery fish ($P < 0.001$, Chi-square = 1,816).

Past studies have shown that age at return may be influenced by growth rate of juveniles in the hatchery environment (Gross 1991). The increased proportion of age-3 jacks in the hatchery population compared to the wild population at Warm Springs may be a result of the increased growth rate of juvenile fish in the hatchery environment. Juvenile hatchery fish at release were larger than their wild counterparts from the 1995 brood year, especially the fall outmigrants (Fig-

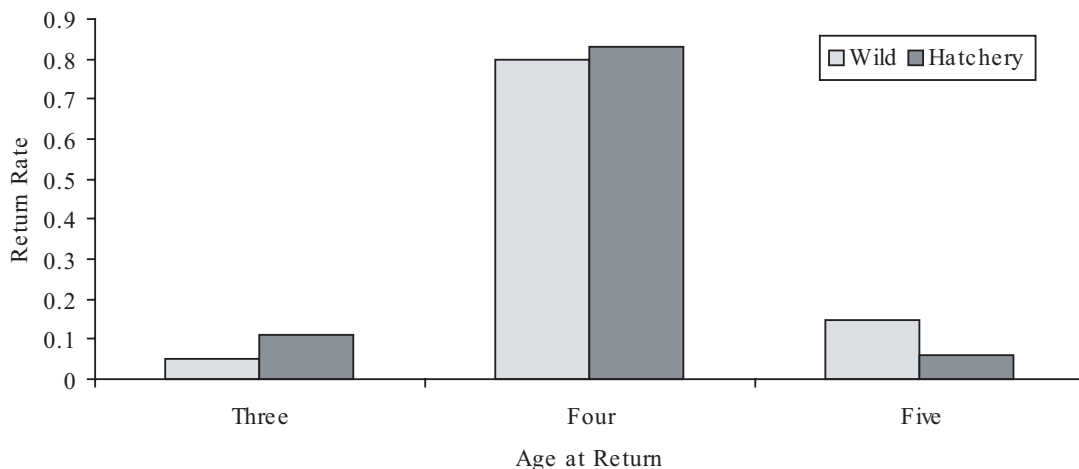


Figure 5. Comparison of age-class strength for wild and hatchery spring Chinook salmon returning to the Deschutes River, brood years 1978–1997.

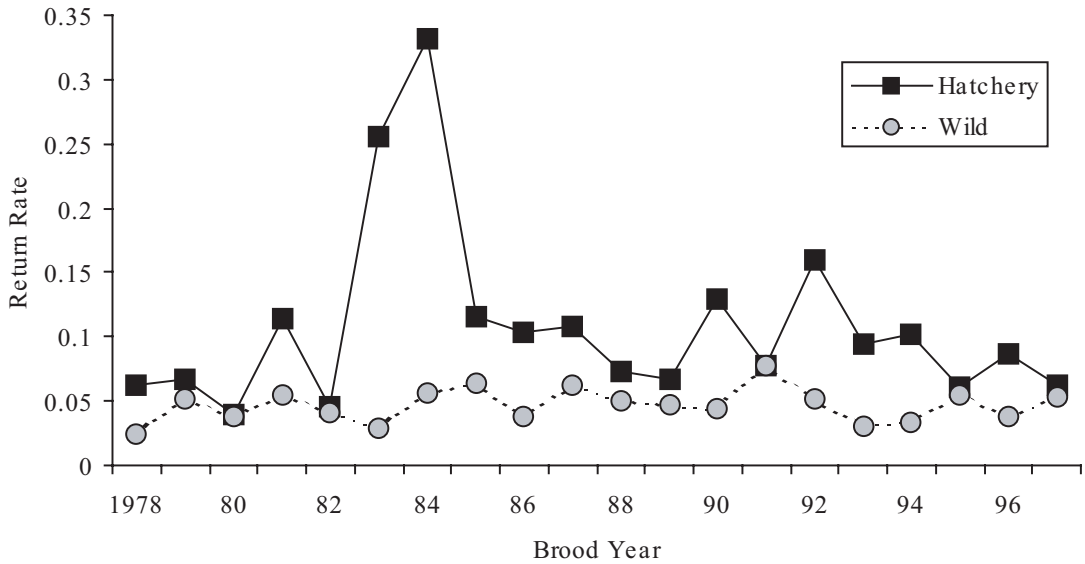


Figure 6. Annual variation in proportion of age-3 (jack) wild and hatchery spring Chinook salmon returning to the Deschutes River, brood years 1978–1997.

ure 7). There was a significant difference in mean fork length between hatchery and wild fish for both the fall ($P < 0.001$, $t = -50.0$) and spring out-migration periods ($P < 0.001$, $t = -17.5$). Specifically, hatchery fish averaged 167 mm (± 2.4 mm, 95% confidence interval [CI]) in fall of 1996 ($n = 448$) and 149 mm

(± 1.8 mm, 95% CI) in spring of 1997 ($n = 851$), whereas wild fish averaged 98 mm (± 1.2 mm, 95% CI) in fall of 1996 ($n = 305$) and 112 mm (± 3.8 mm, 95% CI) in spring of 1997 ($n = 64$). A significant difference was also observed 8 years prior for the 1987 brood year (Olson et al. 1995).

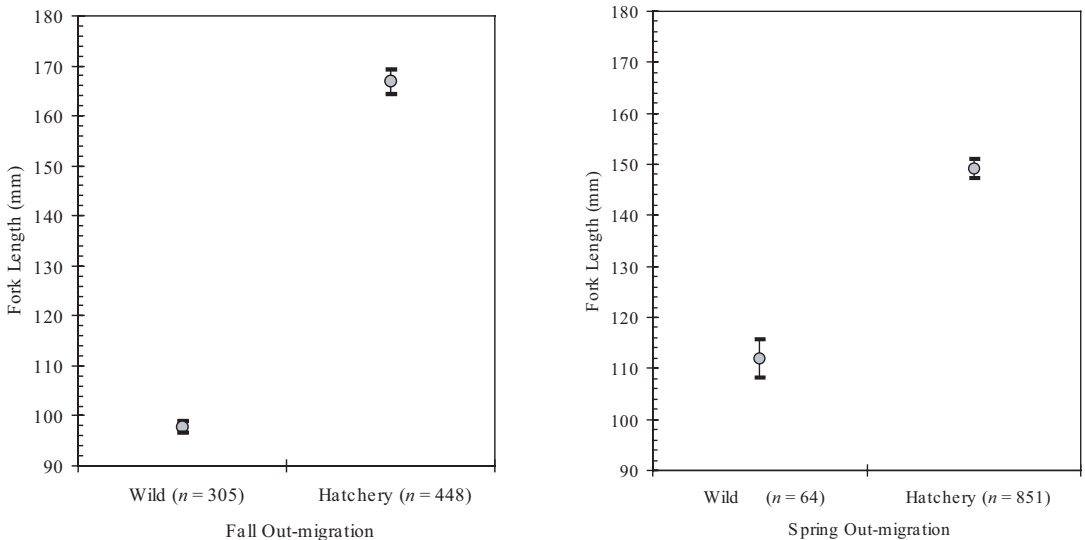


Figure 7. Comparison of fork length (mean and 95% CI) between wild and hatchery juvenile spring Chinook salmon during the fall of 1996 and spring of 1997 (brood year 1995) out-migration periods from the Warm Springs River.

Monitoring will continue to examine size at release and age composition at return to match wild traits in the hatchery population. The original target was to release fish at a size between 26 and 33 fish/kg (12 and 15 fish/lb) and greater than 140 mm average fork length; recently, however, we have experimented with smaller fish at release at 55 fish/kg (25 fish/lb) and 118 mm average fork length. Evaluations will be pursued to effect growth rate in the hatchery environment to match wild fish in the stream, including feeding regimes, diet, and reduced summer water temperatures in the hatchery rearing ponds. The effect upon age at return and survival rates will be investigated as well.

Length at Spawning

We pooled years 1990, 1992, and 1996, when approximately 10% of the broodstock were wild fish, to compare differences in length between hatchery and wild fish. Sex and fork length were recorded from each fish spawned. In general, age-5 fish were larger than age-4 fish, males were bigger than females, and wild fish were bigger than hatchery fish. Specifically for age-4 fish, there was a significant difference ($P = 0.009$) in length between wild ($n = 129$) and hatchery ($n = 1,293$) fish, but no significant difference ($P = 0.135$) between sexes was found (2X2 ANOV model).

The difference in mean lengths between hatch-

ery and wild age-4 females was 1.1 cm (Figure 8), where wild fish averaged 70.6 cm (± 0.9 , 95% CI) and hatchery fish averaged 69.5 cm (± 0.3 , 95% CI). The biological significance of 1.1 cm is questionable, but it may have an influence in the number of eggs produced per female. After examining 24 egg takes at Warm Springs NFH, egg production was positively correlated to the length of each mature female spawned ($y = -1,648 + 63.01x$) and was a significant linear relationship, $P < 0.001$ (Columbia River information System, 10/16/01, Steve Pastor USFWS). Based on this relationship, hatchery fish would produce fewer eggs per female than wild fish of the same age. For example, using this model, a 70-cm female produced 2,763 eggs and a 71-cm female produced 2,826 eggs. Monitoring will continue to determine effects of broodstock collection, the juvenile rearing environment and growth rates upon length composition at adult return, as well as effect on survival.

Marking and Juvenile Production Studies

Marking of juvenile fish at the hatchery has varied over the years, using a mix of chemical marks, fin clips, and tags. Since 1990, all juvenile fish at the hatchery have been externally marked with an adipose fin clip and 100% coded-wire tagged. Juvenile fish were mass marked at the hatchery during their first year of

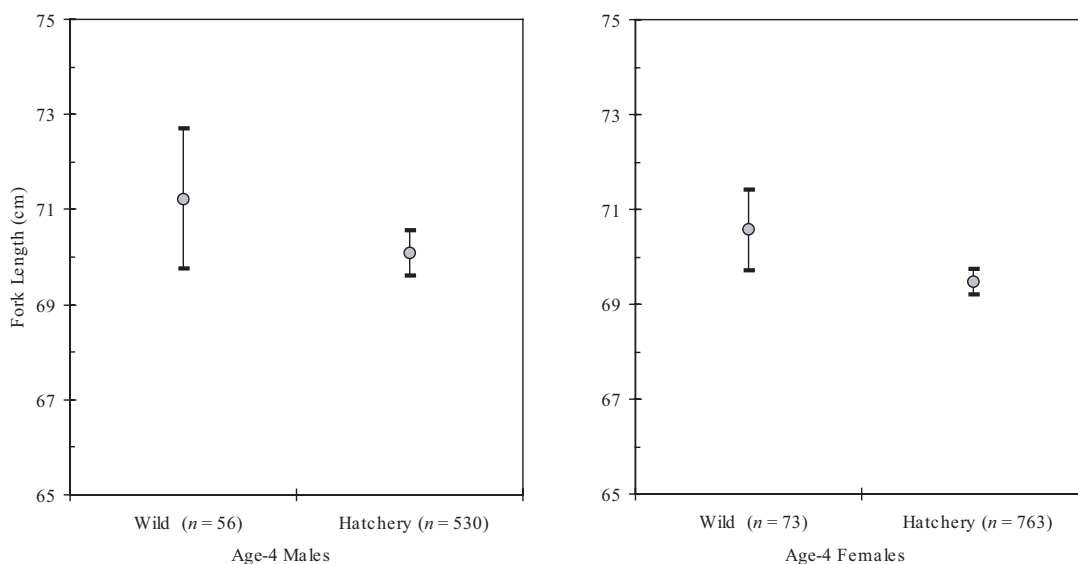


Figure 8. Comparison of fork length (mean and 95% CI) between wild and hatchery adult spring Chinook salmon in the Warm Springs River, sampled at spawning in 1990, 1992, and 1996.

growth, typically in late April to early May when the fish weighed between 287 fish/kg (130 fish/lb) and 441 fish/kg (200 fish/lb). Juvenile fish released from the hatchery were typically split into fall subyearling and spring yearling releases, ranging in size from 18 fish/kg to 55 fish/kg (8 fish/lb to 25 fish/lb) (Olson et al. 1995).

Previous studies at the hatchery were focused on investigation of rearing and release strategies to maximize postrelease smolt to adult survival (Olson 1997). With improved smolt to adult hatchery survival rates observed since brood year 1995 (0.4% to 1.3%), investigations are shifting towards evaluation of growth rates, physiology, and behavior of the hatchery versus wild fish migrating from the Warm Springs River. Enhanced hatchery rearing environments, as discussed in Maynard et al. (1995), will be tested as well. These new investigations involve natural colored rearing environments, live-feed enhancements, variable flow environments, and water temperature adjustments to match the stream temperature profile. Growth rates, condition factor, body coloration, skin reflectance, physiology, and fish health will be monitored, as well as the standard survival parameters at the hatchery. Monitoring both hatchery and wild fish biological characteristics are planned. Behavioral observations may include use of underwater video, direct observations by snorkeling, radio telemetry, and passive integrated transponder tagging and possibly through controlled tank observations.

Rearing density experiments, similar to Banks (1994), are also underway at Warm Springs hatchery to examine the balance between maximum survival rates and adult returns to determine if fewer fish can be released and still achieve the adult returns desired for broodstock maintenance and harvest contribution. Depending on results of our 3-year study conducted on brood years 2000 through 2003, hatchery production could potentially be reduced from the current juvenile production goal of 750,000 to less than 500,000 total smolt production. Reduced rearing densities at the hatchery should also help in fish health management.

Diseases and pathology at the hatchery are closely monitored and managed using fish health management practices as published in policy 713 FW in the Fish and Wildlife Service manual and as described in the 1995 report "Policies and Procedures for Columbia Basin Anadromous Salmonid Hatcheries," by the Integrated Hatchery Operations Team (IHOT 1995). Regularly scheduled fish health examinations at the hatchery are conducted by the Lower Columbia River Fish Health Laboratory of the U.S. Fish and Wildlife

Service. Recent fish health investigations include wild fish within the Warm Spring River.

Hatchery production is typically split into fall and spring release periods, with approximately 10% to 30% of total production volitionally leaving during the fall migration period, mid-October to mid-November. This fall/spring hatchery release technique has been found to be a more successful strategy in returning adults as compared to the former practice of only releasing spring yearling juveniles (Olson 1997). Hatchery fish from the spring release migrate quickly to the Columbia River, with median passage time to The Dalles Dam and the Columbia River Estuary measured at 3–4 weeks after release from the hatchery (Lindsay et al. 1989). However, preliminary results indicate that many of the hatchery fish released in the fall, overwinter in the Deschutes River (Wardell et al. 2002). This migration behavior is similar to their wild counterparts, which also have a fall and spring out-migration period from the Warm Springs River. Wild juveniles leaving the Warm Springs River in the fall also predominately overwintering in the Deschutes River (Lindsay et al. 1989). The balance between maximizing hatchery survival rates and minimizing competition with wild fish will continue to be explored.

Indices of Productivity

Egg-to-Juvenile and Juvenile-to-Adult Survival

Survival at different life stages was compared between hatchery and wild fish, including egg-to-juvenile and juvenile-to-adult survival. The total number of eggs taken and number of eggs per female were estimated by hatchery staff. The eggs per female estimated for hatchery fish was also used to estimate egg deposition for wild fish, where each redd was assumed to represent one female. Adult returns were estimated by combining harvest and escapement for each brood year. A downstream migrant trap located near the mouth of Warm Springs River has been operated since 1976 to estimate wild fish production, out-migration timing, and length-frequency distribution of juvenile fish. Each week, a sample of the fish trapped were marked and rereleased 2 km upstream. Recapture rates of marked fish were multiplied by total catch and fraction of days sampled to estimate the total number of wild spring Chinook salmon emigrating from the Warm Springs River. Wild juvenile spring Chinook salmon exit the Warm Springs River in their first spring as subyearlings (7%), in the fall as subyearlings (57%),

and in the spring as yearlings (36%), brood years 1983–1998. For these same brood years, hatchery juvenile production included a fall subyearling (20%) and spring yearling release (80%). One year, there was also an accidental release of subyearling fish in the spring from the hatchery.

Examining survival data from 1978 to 1996, there was an inverse relationship in egg-to-juvenile and juvenile-to-adult survival between hatchery and wild fish (Figure 9). Hatchery fish had a consistent survival advantage from egg to juvenile (75% versus 9%) and wild fish had a consistent survival advantage from juvenile to adult (2.2% versus 0.3%). These differences between stocks were highly significant for both egg-to-juvenile ($P < 0.001$) and juvenile-to-adult survival ($P < 0.001$), Wilcoxon paired-sample test.

Adult Production

To provide an index of adult productivity, progeny to parent ratios, as defined by adult recruit per spawner (Ricker 1975), were estimated each year since 1975 for wild fish and since 1978 for hatchery fish. The Warm Springs River was established as the reference point for the estimated number of spawners, where the mouth of the Deschutes River was established as the reference point for the estimated number of recruits for each brood year (Lindsay et al. 1989).

The number of hatchery parents (spawners) was determined simply as the total number of fish spawned at the hatchery (males plus females) for each brood year. As described in Lindsay et al. (1989), the number of wild fish spawners was estimated from the number of spawning nests (redds) multiplied by the estimated number of males and females per redd. Spawning ground surveys were conducted by the Tribe and consisted of walking the entire length of potential spawning area in the Warm Springs River (65 km), completing two passes separated by a 1-week interval, timed after the peak spawning period in September. For hatchery and wild fish, the number of progeny from each brood year (recruits) was estimated by combining the number harvested in the Deschutes River (see harvest section) plus the escapement back to the Warm Springs River for each age-class as defined by brood year.

Natural production of adult recruits per spawner (R/S) was cyclical for brood years 1978 through 1997 (Figure 10). Low productivity was observed in the mid-1970s and early 1990s with high productivity observed in the 1980s and recently again in the mid to late 1990s. State and tribal comanagers consider the wild stock a relatively healthy and productive population, averaging 3.2 recruits per spawner (1.9 SD). Hatchery production has been more variable, has increased recently, and has been, on average, comparable to the wild stock, averaging 3.3 recruits per

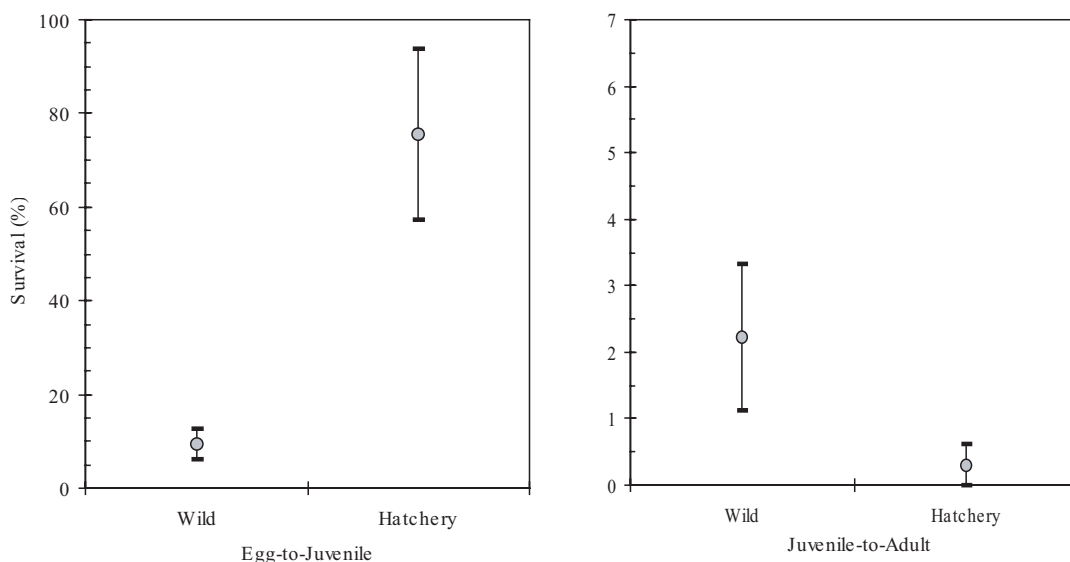


Figure 9. Comparison of egg-to-juvenile and juvenile-to-adult survival (mean and SD) of wild and hatchery spring Chinook salmon from the Warm Springs River, 1978–1996.

spawner (3.9 SD; Figure 10). Wild fish had higher R/S ratios 13 out of 20 years, while hatchery fish had higher R/S ratios 7 out of 20 years; however, this difference was not significant ($P = 0.243$, Wilcoxon paired-sample test). A R/S ratio greater than 1.0 indicates a population that has replaced itself over time, and the Warm Springs population, with a R/S ratio greater than 3.0, is considered healthy and robust (Myers et al. 1998).

Harvest and Escapement

Harvest

Spring Chinook salmon from the Deschutes River are harvested almost exclusively in freshwater fisheries and primarily within the Deschutes River (Olson et al. 1995; Pastor 2000). The primary fishing area for spring Chinook salmon in the Deschutes River is located at rkm 71 near Sherars Falls (ODFW 1997). Tribal subsistence and sport fisheries for spring Chinook salmon in the Deschutes River was monitored by the Tribe and the Oregon Department of Fish and Wildlife. Coded-wire tags were also recovered from hatchery fish to determine contribution from the two spring Chinook salmon hatcheries in the Deschutes River, Warm Springs National Fish Hatchery and Round Butte Hatchery (state of Oregon), as well as any strays from other hatchery programs.

We examined recoveries from Warm Springs hatchery and wild spring Chinook salmon. Both wild and hatchery fish have contributed to harvest. More wild than hatchery fish from the Warm Springs River were often harvested, until recently (Figure 11). Starting in 2000, the state implemented selective fisheries for spring Chinook salmon in the Deschutes River, where only adipose fin clipped hatchery fish could be retained and unmarked (wild) fish were to be released if caught. Improved survival of Warm Springs hatchery fish and restrictive regulations on sport fisheries has led to increased harvest on hatchery fish as compared to wild fish. For example, in return year 2000, almost 2,800 Warm Springs hatchery fish were harvested in tribal (17%) and sport (83%) fisheries, while only 339 wild fish were harvested (95% tribal). A substantial number of wild fish were also caught (1,340) but were required to be released back to the river because of selective sport fishery regulations set by the state. Sport fishers were able to identify marked (adipose fin-clipped) hatchery spring Chinook. With the majority of the Deschutes River harvest accounted by sport fisheries, the objective of this regulation was to reduce sport fishing mortality on wild fish, catch and keep hatchery fish, and have more wild fish returning to the Warm Springs River to spawn.

Based on stock–recruitment analyses by Lindsay et al. (1989), an escapement goal of 1,300 or more wild spring Chinook salmon upstream of the hatch-

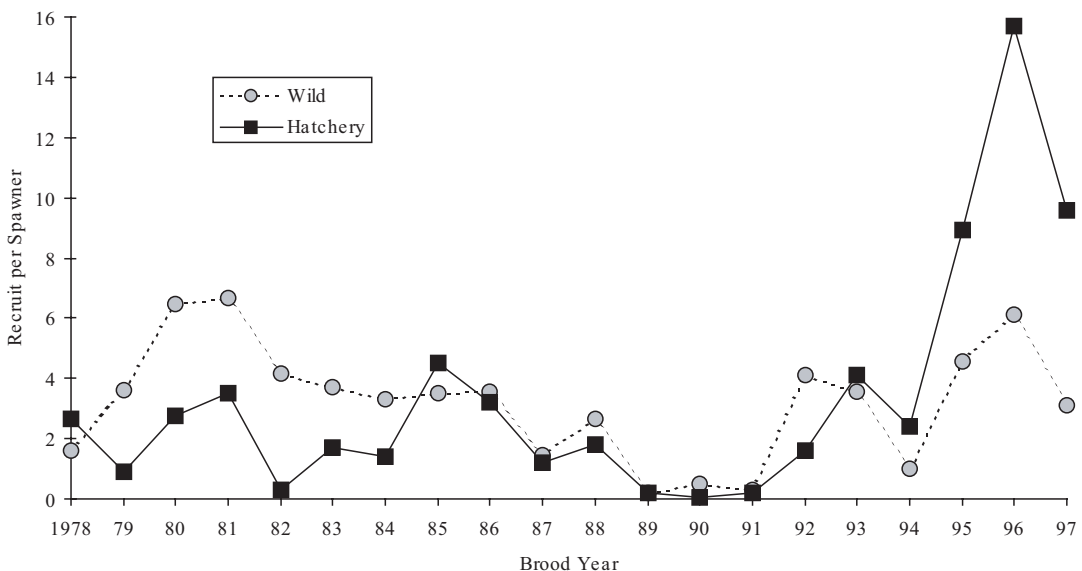


Figure 10. Productivity of wild and hatchery spring Chinook salmon as measured by adult recruit (harvest + escapement) per spawner, brood years 1978–1997.

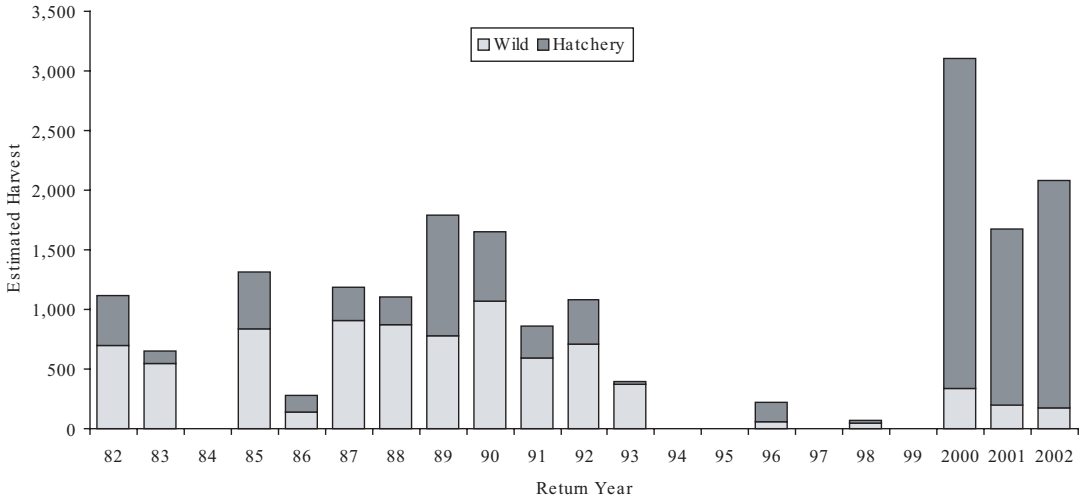


Figure 11. Estimated harvest of Warm Springs stock spring Chinook salmon in the Deschutes River, 1982–2002.

ery has been established by the Tribe, state, and the Service. A wild spring Chinook return projected to be less than 1,300 fish triggers more restrictive fishing regulations by the state and the Tribe. The stock–recruitment information is updated annually.

Escapement

After passing through the fishery, fish return to the Warm Springs River to spawn. Wild spring Chinook

returns have ranged from a low of less than 300 fish in 1995 and 1998 to more than 2,000 fish in 1975, 1976, 1978, 2000, and 2001 (Figure 12). Hatchery returns have ranged from a low of 52 fish in 1994 to recent historic highs from 2,770 fish in 1999 to 6,891 fish in 2002 (Figure 12).

Risks to naturally spawning adult spring Chinook salmon have been managed by limiting the number of hatchery fish on the spawning grounds. However, in early years of hatchery operation, our in-

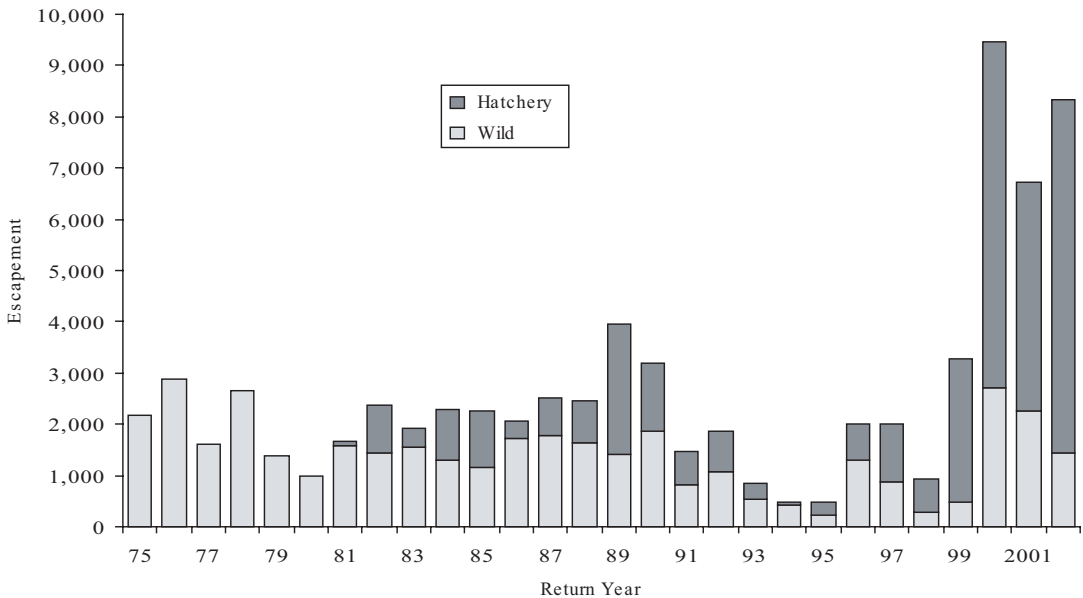


Figure 12. Escapement of wild and hatchery spring Chinook salmon to the Warm Springs River, 1975–2002.

tent was to supplement natural production; not all fish were marked, and up to 30% of the total natural spawners were from hatchery fish passed upstream. Under our current operation plan guidelines, we manage for an allowance of up to 10% hatchery and 90% wild fish upstream. For example, if 1,300 wild fish are passed upstream, then 130 hatchery fish are allowed upstream.

Homing and Straying

Few spring Chinook salmon strays from other hatcheries have been recovered at Warm Springs National Fish Hatchery. In 2000, for example, a total of 2,235 coded-wire tags from spring Chinook salmon were recovered at the hatchery, with only 14 recovered from other hatchery programs (Columbia River information System, November 15, 2000). The hatchery broodstock is believed to include less than 1% of fish from other than Warm Springs origin. Homing of Warm Springs hatchery fish back to the Warm Springs River has been estimated at 97.8% (S. M. Pastor, poster

presentation from the symposium covered by this volume). Of the small percentage that did not return to Warm Springs, most were recovered 31 km up the Deschutes River at Round Butte State hatchery (Pelton Dam), which was also derived predominately from Warm Springs River stock.

Fish Passage and Prespawning Mortality

Management to include hatchery fish in 10% of the natural spawning population upstream of the hatchery is currently adopted, in large part, to reduce handling and prespawning mortality of adult returns. To accomplish this, a newly designed passage system was installed in 1996. Engineers from the U.S. Fish and Wildlife Service designed the passage system to fit in existing catch ponds at the hatchery (Figure 13). The automated passage system includes a modified 15-ft-long Denil steeppass fishway (Bell 1986), a coded-wire tag (CWT) tube detector, and an electric-operated gate that can shunt fish automatically into a hatchery



Figure 13. Automated passage system installed in existing catch ponds at Warm Springs National Fish Hatchery. Looking from right to left, are the denil steeppass weir and coded-wire tag tube detector in catch pond #1, hatchery catch pond #2, and wild catch pond #3 with underwater camera housing.

catch pond or another pond for passing fish upstream. After swimming up the Denil fishway, fish are guided through the CWT detector. If a CWT is detected, the fish is diverted automatically into the "hatchery" catch pond. If no CWT is detected, the fish are diverted into a second "wild" catch pond, from which they swim volitionally past a video monitoring channel (similar to that described by Hatch et al. 1994) and upstream past the hatchery without any direct handling by hatchery personnel. This passage system assumes all hatchery fish are CWT. The passage system is still under modifications and testing and not fully operational because of problems that still need to be corrected, including poor tag retention for hatchery fish in some years (<90%), separating tagged from untagged fish, and automatically sorting fish to the correct catch pond. Nevertheless, the potential advantages of this automated passage system outweigh its technical limitations. Reduced handling and subsequent lowering of prespawning mortality has been accomplished in some years. Automated passage can potentially benefit other wild fish passing the hatchery site as well, including ESA listed bull trout *Salvelinus confluentus*.

From 1977 to 2002, the prespawn mortality of spring Chinook salmon passed upstream of the hatchery to spawn naturally (both wild and hatchery fish) was estimated at 48% (13% SD).² Spring Chinook salmon kept for broodstock at the hatchery typically had less than 20% prespawn mortality, except for the first 4 years of hatchery operation (41%). Bacterial kidney disease *Renibacterium salmoninarum* was suspected as one of the primary causes of high prespawn mortality, especially in 1980 and 1981 for both the naturally spawning population (74% mortality) and hatchery broodstock (48% mortality). Because of this, erythromycin injections have been administered since 1982 to all hatchery and wild adult spring Chinook salmon either passed upstream or kept for broodstock. After using erythromycin, the prespawn mortality of

fish passed upstream of the hatchery averaged 46% (9% SD), 1982–2001. However, in 2002, an unusually high prespawn mortality occurred with hatchery broodstock (44%) and fish passed upstream (74%) due to warmwater temperatures, furunculosis bacterial infections, and high parasite *Ichthyophthirius* (Ich) loading on the fish. In addition to high water temperatures, the amount of handling on fish as they return to the hatchery may contribute to fish health problems and prespawn mortality. As previously discussed, operation of the volitional passage system is being investigated to reduce handling of fish passed upstream of the hatchery, to subsequently reduce the risk to fish of contracting a disease, and to reduce prespawning mortality.

Also at the hatchery, new intake screens are being installed in 2004 to meet NOAA Fisheries and Service specifications for juvenile salmon, steelhead, and bull trout. The screens currently in place were determined to be out compliance in 1996. Since the water supply for the hatchery is the Warm Springs River at the hatchery site, new intake screens, as specified, will improve in-river passage of fish.

Conclusion

This paper was a discussion of the operation of Warm Springs National Fish Hatchery, a modern hatchery with conservation goals, compared to the pre1960 hatchery model described in the Northwest Power Planning Council's artificial production review documents (Brannon et al. 1999). The old model includes transfers of fish between basins, artificial selection and domestication, success measured in terms of smolt production, and so forth, while the new paradigms include production based on the indigenous stock, avoiding selection, managing ecological and genetic risks, conserving the native stock, and monitoring success in terms of return to the fishery and reduction of adverse impacts. The Warm Springs program is a model of describing conservation recommendations for management of a production facility—even though the hatchery was designed and put into operation many years prior to the currently popular push for hatchery reform.

Genetic conservation and demographic protection of the naturally spawning population in the Warm Springs River have been priority objectives by the state, Tribe, and U.S. Fish and Wildlife Service since the start of hatchery production in 1978. The Warm Springs National Fish Hatchery represents a model program for integrating natural reproduction and ar-

² Prespawning mortality rate for hatchery fish was determined as the number of mortalities in the catch ponds divided by the total number collected for broodstock. Prespawning mortality of fish passed upstream of the hatchery until the time they spawned in the fall was estimated from counts of fish passed upstream of the hatchery, sex ratios of broodstock at the hatchery, and redd counts above the hatchery (Lindsay et al. 1989). Mortality estimates were based on the assumptions that each redd represented the completed effort of one female and that the number of redds outside of survey areas was negligible. Prespawning mortality was the difference in the estimated number of females passed upstream of the hatchery and the number of redds.

tificial propagation of Pacific salmon within this watershed. All hatchery-origin fish are marked and tagged prior to release, and this allows the proportion of natural and hatchery origin adult fish in the broodstock and on the spawning grounds to be monitored and controlled. The hatchery has increased productivity and carrying capacity for spring Chinook salmon of the Warm Springs River compared to the natural habitat alone. As a result, the hatchery has increased the number of harvestable adults returning to the Warm Springs River by as many as 2,000–3,000 fish. Moreover, hatchery-origin fish can potentially represent a genetic repository for the naturally spawning population, should a catastrophic environmental event or major fish kill ever occur. Such an event occurred in 1999 when a gasoline tanker truck crashed and spilled its load into a tributary of the Warm Springs River.

The spring Chinook salmon program at Warm Springs National Fish Hatchery can serve as a model for other integrated hatchery programs where both harvest and conservation goals are a priority. This hatchery program is clearly providing harvest benefits and potentially can provide long-term conservation benefits while posing minimal biological risks to the naturally spawning population in Warm Springs.

Research and monitoring are an integral component of this program because of the unique opportunities afforded by the facility and the management goals for the hatchery broodstock. Because differences between the wild and hatchery population of spring Chinook salmon in the Warm Springs River have been noted (S. Rubin, R. Reisenbichler, L. Wetzel, and F. Leonetti, podium presentation from the symposium covered by this volume), experiments will continue to determine if wild fish life history characteristics can be maintained in a hatchery environment. Studies will continue on broodstock management practices as well as changing the hatchery rearing environment, such as reduced rearing densities; creating water temperature profiles to match the stream environment; matching growth rates, size, and timing of downstream migration; and introducing natural feeds. Further investigations of ecological interactions between hatchery and wild fish, along with determining the reproductive success of hatchery fish spawning in the stream, are also being explored (D. M. Hand, R. O. Engle, T. A. Hoffman, D. E. Olson, G. FitzGerald, and B. Spateholts, poster presentation from the symposium covered by this volume). Changes are made to the hatchery program based on this research and monitoring, as described in the Hatchery and Genetic Man-

agement Plan and in the 5-year hatchery operations and implementation plan.

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